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AN AUTOMATED COORDINATE MEASUREMENT SYSTEM FOR SMOKE TRAIL PHOTOGRAPHS,

(10)

Christian A./Trowbridge
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PhotoMetrics, Inc.
442 Marrett Rd., Lexington, MA 02173

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A semi automatic Coordinate Measurement System for Photographic imagery is described. The system features the use of computer directed film transport motion and video densitometry to locate, measure, and record the positions of smoke trail images which are utilized to trace the stratospheric field. used

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FOREWORD

The program described here consisted of the design and construction of hardware and software modifications to enable the existing *AFGL Video Densitometer System* to be utilized as a Coordinate Measurement System. Photographic images of Stratospheric smoke trails reduced by the system are used to determine profiles of horizontal wind.

The authors wish to express their thanks to Dr. Antonio F. Quesada (Technical Monitor) of AFGL for his continued encouragement and support, to Dr. Norman W. Rosenberg for invaluable assistance in suggesting algorithms and reviewing software solutions, and to C.C. Rice who also made important contributions to this report.

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SECTION I

SUMMARY AND OVERVIEW

The objective of this program is to design and implement a Coordinate Measurement System By Hardware and software modification of the AFGL Video Densitometer System (Ref 1). The system was subsequently used to scan and record digital positional information from photographs of star fields (to obtain precise camera orientation) and of stratospheric smoke trails which trace the motion of stratospheric winds. The data thus reduced has been transmitted to AFGL scientits for further analysis and interpretation.

Descriptions of hardware modifications and additions are contained in Section II and in the hardware manual which contains all vendor supplied information and descriptions of any changes made to the equipment or circuits. Section III outlines the approach taken to the design of the measurement system; further details may be found in the software manual which also contains listings of all programs written. The entire hardware and software documentation has not been reproduced here because of its extremely large volume (approximately 800 pages) but two copies have been made a permanent part of the substantial library of information which describes the original configuration of the AFGL Video Densitometer.

Details of the operating procedures for the Coordinate Measurement System are set forth in Section IV while Section V describes operator setup and intervention procedures which should result in highest system efficiency.

SECTION II

Hardware Configuration

The hardware may be regarded as consisting of two interacting subsystems: a video densitometer subsystem and a film transport subsystem. A dedicated small computer controls the overall system and is a part of both subsystems, as is a teletype unit used for communication and control. A block diagram of the system is shown in Fig 1.

A. Video Densitometer

The video densitometer subsystem consists of a vidicon television camera with a video control center, light table, color monitor, disk storage unit, magnetic tape unit, and analog-to-digital and digital-to-analog converters (ADC and DAC).

1. Vidicon. The vidicon views an 8 millimeter square portion of the film as transilluminated by the light table, and produces an analog rendering of optical transmission as a function of position. The control center permits adjustment of the upper (white) and lower (black) video thresholds, and thus allows different illumination levels to be represented by midrange (i.e., unsaturated) video signal levels.

2. Disk Unit. The disk unit stores the image as digitally encoded by the ADC. An 8-bit range (0 black to 255 white) is used to render the 384 by 384 picture element (pixel) image and a 2-bit graphics signal is also stored for each pixel. Digitization of the video frame requires 1/30 second. Approximately one quarter of the disk capacity, not required for the image, is used to store the system program.

3. Color Monitor. The color monitor displays either the data directly from the camera or the image on the disk converted to analog. In either case, a color contoured image is displayed. Pixels with digital value (D.V.) 255 are displayed as white, values from about 229 to about 254 are displayed as light blue, 203 to 228 as dark blue, etc. Pixels of digital value 0 are displayed as black, 1 to about 25 as violet, about 25 to 50 as magenta, etc. This display, which is manually

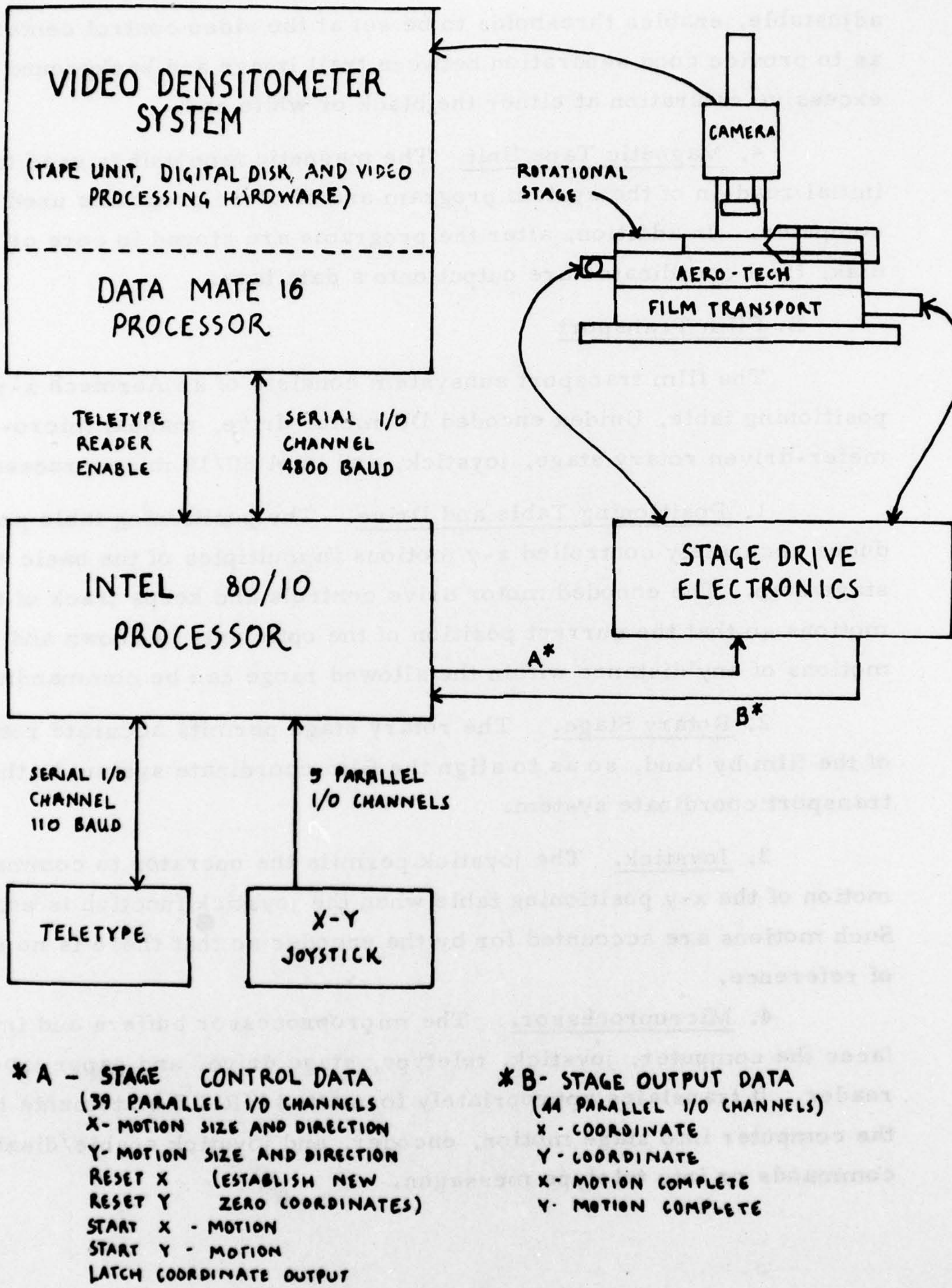


Figure 1. Block diagram of the Coordinate Measurement System.

adjustable, enables thresholds to be set at the video control center so as to provide good separation between trail image and background with excessive saturation at either the black or white end.

4. Magnetic Tape Unit. The magnetic tape unit is used for initial read-in of the system program and of other programs used by the computer. In addition, after the programs are stored in core or on the disk, trail coordinates are output onto a data tape.

B. Film Transport

The film transport subsystem consists of an Aerotech x-y positioning table, Unidex encoded DC motor drive, manual micrometer-driven rotary stage, joystick, and Intel 80/10 microprocessor.

1. Positioning Table and Drive. The positioning table produces accurately controlled x-y motions in multiples of the basic $4\mu m$ stage step. The encoded motor drive controls and keeps track of these motions so that the current position of the optic axis is known and motions of any distance within the allowed range can be commanded.

2. Rotary Stage. The rotary stage permits accurate rotation of the film by hand, so as to align the film coordinate system to the transport coordinate system.

3. Joystick. The joystick permits the operator to command motion of the x-y positioning table when the joystick function is enabled. Such motions are accounted for by the encoder so that there is no loss of reference.

4. Microprocessor. The microprocessor buffers and interfaces the computer, joystick, teletype, stage drive, and paper tape reader. It translates appropriately formatted WRITE statements from the computer into stage motion, encoder, and joystick enable/disable commands or into teletype messages.

C. Computer Control

The computer provides overall control and integration of both subsystems. The system program resides on the disk and portions are read into core storage as necessary. Digitization of the video image occurs on command from the computer, which then analyzes selected portions to determine what action should be taken next. On the basis of the decisions, tape records are written, stage motions commanded, or messages printed requesting operator intervention.

SECTION III

System Concept

Guiding the system through the task of digitizing a smoke trail requires that the operator understand the steps which must be accomplished. Before setting out the procedural details, it is therefore useful to sketch the system concept.

When the smoke trail is produced, it is nearly straight and vertical. Variations in wind velocity with altitude introduce distortions as time goes by. A trail which is one minute old may have kinks and closed loops and will certainly have a complex, tortuous shape.

The system computes the x- and y-coordinates of a closely spaced (typically about $25\mu m$) series of points whose locus is the center of the trail image. Because accurate work is possible only at the optic axis, this axis must be moved along the path of the trail. A system to perform this task unassisted would require an unacceptable investment in both hardware and software. Assistance is therefore provided by the operator through entry of a skeleton trail. This series of points is much more widely spaced than the points recorded by the system, and the skeleton points need not be accurately centered on the trail. The skeleton points serve to specify the general direction of the next segment of the trail; this is usually enough guidance to permit the system in automatic mode to direct the optic axis along the trail and locate the center at numerous intermediate points.

The system assigns a digital value (D. V.) to each pixel. These values range from 0 (displayed as black on the color monitor) to 255 (white on the monitor) and are proportional to the light detected by the vidicon. They therefore vary inversely with photographic density. The dark trail and relatively clear background are assigned low and high D. V. respectively.

The response of the camera varies with position relative to the optic axis. Maximum accuracy is therefore achieved only when points on the film are compared by placing each in turn on the axis. Approximate digital values can, however, be obtained for off-axis points; these are used in determining rough stage motions, the fine corrections being made by moving the stage one step at a time and comparing axial values.

In practice the camera is fixed and the film is moved in the x-y directions on a positioning table. The purpose of these motions is to place different pixels on the optic axis. It would be equivalent to move the optic axis to different points on the film by moving the camera. We shall therefore speak for brevity of moving the optic axis.

Fine locations are made on the assumption that the trail center is midway between the trail edges, (determined by a thresholding process). When the optic axis is at a skeleton point, the system computes the slope of a straight line to the next skeleton point. Scanning to determine the position of the trail edges will be along a line approximately perpendicular to the line between skeleton points; the actual scan direction will be parallel to the horizontal or vertical coordinate axis or at 45^{o}. The most dense (lowest D.V.) point along this scan line is initially chosen as the center pixel. Points far from the center define the maximum D.V. or background and the edge of the trail, is taken as the mean of these values. The location of the trail center is taken as the midpoint between the trail edge coordinates - i.e. those having this background D.V. This location is stored for transfer to magnetic tape. The system automatically moves the optic axis a small distance, roughly toward the next skeleton point, and whole process is iterated.

A halt occurs when the system encounters a situation which requires operator intervention. Such situations arise when:

1. The scan line intersects the trail at more than one point.
2. The thresholds are so set that a trail edge is not found, or a large fraction of the pixels have digital value 255 (too much white) or 0 (too much black).

3. Moving the optic axis the specified distance toward the next skeleton point places the point of maximum density (minimum digital value) too far along the scan line from the optic axis; the system can sometimes recover from this excessive shear condition without operator intervention, by reducing Δx. In most cases, the operator must recognize the cause of the request for intervention and take corrective action as described in Section V.

The basic steps in operating the system are the following:

1. Load the system program from magnetic tape to disk and core storage.
2. Mount the data tape and set the thresholds.
3. Correct rotational misalignment between film and stage coordinates.
4. Establish the coordinate system using fiducials or frame edges.
5. Use the joystick to enter the skeleton trail, and start the system digitizing.

Details of these steps are given in Section IV, while intervention and setup for improved efficiency are discussed in Section V.

SECTION IV

Operating Procedure

A. Loading the System Program

1. Apply main power to computer digitizing system, disk, microprocessor, teletype, positioning system, tape drive, vidicon, video densitometer and monitors.

2. Mount system tape. Press LOAD twice followed by ON LINE.

3. Use key to turn computer ON, then to ENABLE.

4. Turn teletype to ON LINE. Press reset on microprocessor. Type*

   G 800 (CR)

   G 800 (CR)

   G(CR)

   If at any time the break light comes on,depress the BRK RLS Button.

5. Set 017000 (octal) on the switch register. Execute the switch cycle:

   SI

   KR

   ENT

   RUN

6. Teletype prints

   PROGRAM NAME:

   Type

   TSEG0 (CR)

7. Set 000410 on the switch register and execute the switch cycle.

* (CR) will be used consistently to indicate the RETURN key.

8. Teletype prints

ENTER SEGS TO LOAD 12

Type

16 (CR)

Program is read from tape.

B. Setting the thresholds

1. Teletype prints

SYSTEM LOADED

DO YOU WANT A SPECIFIC SEGMENT

Type

(CR)

to enter normal sequence. (This point can be reached at any time by setting 000413 on the computer and executing the switch cycle. It is then possible to branch to various parts of the program as described in Section V-D.)

2. Teletype prints

REMOVE TRISYS TAPE-MOUNT DATA TAPE

Press ON LINE (so ON LINE light goes out) Press REWIND--- remove tape. Mount data tape, press LOAD twice, press ON LINE.

Teletype prints

ENTER DATA FILE NO. 12

Enter the number of the file to contain the coordinate data for this data frame. If it is a one digit number it must be preceded by 0. Press CR.

3. Teletype prints

SET VIDEO POLARITY FOR DARK OBJECTS
ON LIGHT FIELD.

PLEASE CHECK MAGNIFICATION FOCUS
AND F NO, THEN SET THRESHOLDS

Set thresholds at video control centers press CR to see the new setting displayed in the digitized picture. Teletype prints the last time above. Thresholds can be reset as many times as desired. When the thresholds are acceptable, type

4. Teletype prints

MOVE STAGE TO LEFT SIDE FIDUCIAL-TYPE CR

Place the optic axis on the left edge of the film frame.

Type

CR

5. Teletype prints

ENTER FIDUCIAL TYPE-TRIANGULAR + NONE -
1, 2, 3, -12

Type, for example,

03 CR

to use frame edges as the reference.

6. Teletype prints

MOVE STAGE TO TOP LEFT OF FRAME –

Type

CR

7. System makes fine position adjustment, then the teletype prints

MOVE STAGE TO TOP RIGHT OF FRAME

Type

CR

Use the joystick to position the optic axis at the top edge of the frame near the right edge.

Type

CR

8. System makes fine position adjustment and computes the rotational misalignment.

Teletype prints

MISALIGNMENT = NNN STEPS

ROTATE STAGE CW (CCW) ± X.XXX MM

WHEN DONE – TYPE CR

Rotate micrometer advance clockwise (counter-clockwise) as specified. One major division ≈ 0.001 mm.

Type

(CR)

If the rotational alignment = 1 stage step, or less the teletype prints

MISALIGNMENT = 0(1) STEPS

Y COORDS OF TOPE EDGE

XXXX XXX

D. Establishing the Coordinate System

1. Teletype prints

MOVE STAGE TO LEFT CENTER EDGE

Type

(CR)

Place the optic axis on the left edge of the frame near the center.

Type

(CR)

2. Teletype prints

MOVE STAGE TO BOTTOM CENTER EDGE –

Type

(CR)

Place the optic axis on the bottom edge of the frame near the center.

Type

(CR)

3. Teletype prints

MOVE STAGE TO RIGHT CENTER EDGE –

Type

(CR)

Place the optic axis on the right edge of the frame near the center.

Type

(CR)

4. Teletype prints

   COORDS LEFT, RIGHT, TOP BOTTOM

   XXX XXX XXX XXX XXX

   At this point a (0, 0) coordinate reference will be established at the frame center.

   ENTER STAR CALIB OR TRAIL TRACE-1 OR 2-12

   Type

   01(02) (CR)

   for star (or trail) digitization.

5. If 02 was entered, the teletype prints

   APPROXIMATE TRAIL ENTRY PROGRAM

   ENTER TRAIL ID FOR TAPE

   SITE SITE TIME XXX XX MM/DD/YY NAME NAME

   Type identifying information followed by two (CR)

6. Teletype prints ..

   Place the optic axis over the point selected for the next skeleton point.

   Type

   EN (CR)

   when two or more points have been entered the .. response changes to H .. V .., or D .. (Horizontal, Vertical, Diagonal) to indicate the scan mode which will be selected when coordinate measurement begins.

7. To delete the last point, type

   DL (CR)

   To list skeleton points type

   LI (CR)

   All skeleton points should be listed before exiting. When all skeleton points have been entered and listed, type

   EX (CR)

8. Teletype prints

EXIT TRAIL TRACE M

where M is the number of skeleton points

ENTER DELTA X IN STAGE STEPS -I2

Type Δx, the parameter used to compute the maximum distance between digitized trail points (typically, about 5 or 6) followed by (CR). Digitization commences.

SECTION V

Operator Functions

A. System Philosophy and Function

The system philosophy envisions an operator who is present or within call at all times. In addition to actual operation of hardware, this person has two principal functions:

1. Initiation of the run by entering of a series of skeleton points which will permit accurate and rapid automatic trail following with a minimum of operator intervention.

2. Intervention when the system encounters situations which it cannot deal with automatically.

Requests for operator intervention occur when the system performs a test and in consequence recognizes that intervention is needed. A message is printed requesting the operator to take action. Appropriate response and proper initial selection of skeleton points require that the operator have the knowledge of the system's programmed operation provided in this section.

Starting immediately after a trail center point has been located and recorded, the system performs the following cycle of operations in the course of locating the next trail center point:

1. The optic axis is moved a distance toward the next skeleton point. If the skeleton point is not reached, the cycle continues.

2. The scan direction is chosen on the basis of the slope of the line between the last skeleton point and the next skeleton point.

3. The optic axis is moved along the scan line to the center pixel; the pixel of minimum digital value (D. V.).

4. The pixels of maximum D. V. are found along the scan line to either side of the center pixel.

5. The overall maximum D. V. is defined as the mean of the maximum D. V.'s to either side. The background is defined as the mean of the maximum D. V. and the D. V. of the central pixel.

6. A search is made from the center outward along the scan line for the first pixel to either side at which the background D. V. is exceeded: the trail edge pixel.

7. The axis is moved to each trail edge pixel in turn for fine trail edge location. During fine location, the axis is moved one step at a time until final establishment of the location of the trail edge on each side of the trail.

8. The axis is moved to the midpoint between these two trail edges. This is the location which is recorded as the trail center. The system returns to Step 1 and the cycle is repeated.

The system performs a number of checks during this cycle. In Step 1, a check is performed to determine whether the motion will bring the axis past the skeleton point. If so, the axis is initially moved to the skeleton point; then the scan direction is chosen on the basis of slope of the line to the following skeleton point and the cycle is picked up from Step 3. No intervention is normally required.

Step 2 sets the scan direction using an algorithm based on the slope of the line between skeleton points:

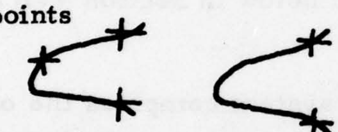
Scan horizontal if $/S/ > 1$ (trail roughly vertical)

Scan vertical if $/S/ < .5$ (trail roughly horizontal)

Scan diagonal if $.5 < /S/ < 1$ (trail diagonal).

The sense of the diagonal scan ($+45^\circ$ or -45° is the sense more nearly perpendicular to the line to the skeleton point; i.e., -45° if $S > 0$ and $+45^\circ$ if $S < 0$.

Trail center location is very much faster if the scan is horizontal, because then data from only a single line of the disc need be read for use in Steps 4, 6 and 7. Efficiency is thus much greater if as much of the trail as possible is spanned by more or less vertically disposed skeleton points

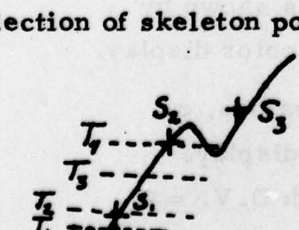


+ = skeleton points

For example, the sketch shows a segment of trail with two possible choices for skeleton point locations. The choice on the left leads to a vertical scan. The one on the right might run dozens of times faster because the scan direction will be horizontal.

Step 3 places some of the key constraints on skeleton point selection. The pixel of maximum density along the scan line is defined as the center pixel. If the scan line intersects the trail at more than one point, or if the trail departs substantially from perpendicularity to the scan line, this center pixel may be far from the optic axis. The latter case, excess shear, can be handled by the system. In the case of multiple trail-scan line intersections operator intervention may be necessary.

Intersection of the scan line with the trail at more than one point results from the tortuousity of some trails, or from injudicious selection of skeleton points. In the figure the line connecting skeleton points S_1 and S_2 is nearly vertical so the scan lines will be horizontal. The scan lines at T_1, T_2, and T_3 will lead to acceptable trail points,



and the optic axis will move to a point on the line T_4. This line intersects two different segments of the trail, and if the density is higher (digital value lower) at the right-hand intersection; the center pixel will be chosen in this region. If digitization proceeded from this point a segment of the trail would be skipped.

In the example, the problem could have been avoided by placing S_2 near the center of scan line T_3. The segment from S_2 to S_3 is nearly horizontal and a vertical scan would be used. Such a scan line would intersect only one section of the trail. The loop shown in the next example cannot be handled in this way, as no scan direction can

avoid multiple intersections with the trail.

Some of the options described below in Section V-B are useful in dealing with this situation.

To sense these problems the system computes the offset of the center pixel from the optic axis. If this offset exceeds a predetermined value, currently 20 pixels, the error routine is entered and the teletype prints a message. The situation can be recognized from the printed value of CENTER PIX.

During Step 4, the data are tested. If too many pixels have saturated D. V. (off scale white) or zero D. V. (off scale-black) or if the ratio of background to trail D. V. is too low(ΔD not large enough) an error message is printed. The standard fix is to change the threshold settings but it is also possible, as described in the next section, to enter the standard error routine and use of any of the options provided. An error message is also printed if there are multiple maxima and minima in D. V. along the scan line.

The threshold should be set so that:

1. the trail is digitized at low values as s[illegible] v by black, violet, or magenta in the co[illegible]ay.
2. the background is digitized at high v[illegible]s, as shown by white or blue in the color display.
3. there are a few pixels (or none) with D. V. = 0 or D. V. = 255.

B. Standard Error Routine

Most requests for operator intervention result from shift of control to a routine in Part IV of the digitization routine. The teletype prints

```
P     BKG = (a)     CENTER PIX = (b)     SHEAR = (c)
SKELETON Pt = (c)   VIDEO LIMIT = (e)    DX    = (f)
      PT     XVAL     YVAL
      (g)    (b)      (i)
      ___    ___      ___
      ___    ___      ___
      TRACE IS        (j)
```

where

(a) is the background value, i.e., the D. V. of the trail edge pixel

(b) is the offset in pixels of the pixel of minimum D. V. (center pixel) from the optic axis

(c) is a function of the offset in the scan direction divided by the offset perpendicular to the scan direction

(d) is the number of the current skeleton point

(e) is the number of pixels, from the center, searched in looking for the trail edge pixel

(f) is Δx in stage steps

(g) is the point number and (h) and (i) the stage X- and Y-coordinates of each of the last four points digitized

(h) is the orientation of the scan line.

(The first time this routine is entered a summary of available options is printed.)

The message

ENTER OPT I2

is then printed, and the operator specifies the action to be taken by entering the two digit number:

01 The axis is moved to the next skeleton point and digitization continues from there.

02 Points which have been digitized are written onto the magnetic tape and digitization terminated: frame is assumed finished.

03 Trail point locations are entered directly using the joystick. The teletype prints

ENTER NO. OF JOYSTICK VALUES I2

The number of such points is entered as a two-digit number. The teletype prints

MOVE STAGE TO NEXT POINT-TYPE CR

The optic axis is moved, using the joystick and the stage coordinates are taken as trail points: the process is repeated for the number of such points specified. After each (CR) the image is redigitized so the exact location of the point entered can be seen. If the last such point results in motion beyond the next skeleton point the axis is moved to the skeleton point.

04 Restriction of background search. The teletype prints

ENTER NEW BACKGROUND I3

The operator enters the background value as a 3-digit number. The location of the next trail point will be taken midway between the points where this value is reached. For subsequent points the system reverts to the standard method of determining the threshold.

05 Change Threshold. The teletype prints

CHANGE THRESHOLDS - TYPE CR

There are three sub-options:

i) Adjust thresholds and type (CR). Digitization begins anew at the same starting point.

ii) Type a positive number. The optic axis moves a distance Δx toward the skeleton point and this location is recorded as a trail location. The axis then moves to the next starting point. If insufficient density range or too much black is encountered, interpolation toward the skeleton point continues. Otherwise the system reverts to normal operation.

iii) Type a negative number. The beginning of the main error routine is entered. (The message ENTER NEW BACKGROUND can be reached by other routes as described below; responding with a negative number makes available all the options described in this section.

06 Ignore value and increment. No further attempt is made to digitize the point. The axis is moved to the next starting point to try again.

07 Enter center pixel. Teletype prints

ENTER CENTER PIXEL

The operator enters the pixel at which the approximate trail center (normally the point of maximum density, pixel 192) is assumed located.

Teletype prints

ENTER SEARCH LIMIT -- I2

Operator enters the number of pixels from this center to the limit of search for a minimum. Fine location of the trail edge continues with this value.

08 Change scan direction: Teletype prints

ENTER DIRECTION-1 THROUGH 4-I2

The scan direction resulting from the number entered is

01 -- horizontal

02 -- vertical

03 -- -45^{o}

04 -- $+45^{o}$

Requests for operator intervention can occur without this full sequence. There are four such entry points. Three eventually result in an opportunity to enter the main error routine. In these cases the teletype prints one of the following messages:

DELTA D NOT LARGE ENOUGH

TOO MUCH DATA OFF SCALE-BLACK

TOO MUCH DATA OFF SCALE-WHITE

In each case the teletype then prints

CHANGE THRESHOLDS-TYPE CR

The operator has the same three options that are available when this message is printed after selection of option 05 in the standard error routine.

The final error sequence is entered when the scan encounters multiple maxima and minima in digital value.

The teletype prints

BKG = ______________

MULTI MAX DATA MIN-MAX ORDER

PT	Val
___	___
___	___
___	___

with a list of pixel numbers and digital values of the maxima and minima. The message continues

AUTO BKG INDEX =

___ ___

with a printout of the pixel number to each side of the trail at which the minimum value was found. Then the teletype prints

ENTER NEW BACKGROUND I3

The operator enters a D.V. which is used for locating the trail center for that one point.

C. Use of Error Routine

Each item of information provided in the request for operator intervention has a particular significance, and each option is designed to cope with one or more particular situations.

The significance of the items of information may be summarized as follows:

1. Background Value

The digital value (D. V.) associated with the trail edges. If it is too high, the search for a pixel with this D. V. may extend too far from the trail center and intersect another segment of the trail.

2. Center Pixel

The number of the pixel with the lowest D. V. along the scan line, initially taken as the trail center pixel.

3. Shear

The quotient four times the offset in pixels of the center pixel from the optic axis divided by three times Δx in stage steps. This is a measure of how far the trail direction is deviating from perpendicularity to the scan direction; if it gets too large Δx will be reduced from the initially input value.

4. Skeleton Point

Given the number of the current skeleton point, its coordinates and those of the next skeleton point can be read from a list which should be generated after the skeleton points are entered.

5. Video Limit

The number of pixels from the optic axis (pixel 192) that will be searched in looking for the center pixel.

6. DX

The number of stage steps between points at which trail center coordinates are determined. A stage step is $4\mu m$.

7. Last Four Points Digitized

These may not appear in order; the order is taken from the number associated with each point. The coordinates, along with those of the skeleton points, indicate where the axis is moving.

8. Trace Direction

The direction of scan can be compared to positions of successive points to determine whether the scan is nearly perpendicular to the trail.

The various options may be useful in the following cases among others:

Option 01. If the last point digitized is near the next skeleton point, it may not be worth struggling; this option may be used to get beyond a difficult region by proceeding to the next skeleton point. If the axis has wandered far from the trail, this option may also serve in returning to a useful region. The drawback, of course, is that a segment of trail is skipped.

Option 02. If part of a trail has been digitized successfully, and problems then arise, it may be useful to exit. It is then possible to enter a new set of skeleton points and continue from the point at which trouble arose.

Option 03. Certain trail segments cannot be properly digitized in automatic mode; points where the trail crosses itself represent an example. Manual entry of the points using the joystick allows such regions to be handled.

Option 04. If the background D. V. computed in automatic mode is too high, search for the trail edge may extend far enough to encounter spurious signals. Manual entry of a lower background D. V. can solve some problems arising in this way.

Option 05. The video control center can be used to modify the D. V. that will be assigned to each pixel; the effect is somewhat similar to changing the light level. Excessively high or excessively low D. V., or insufficient separation of the trail from the rest of the scene, can be handled in this way.

If a positive number is entered trail locations are found by interpolating toward the next skeleton point. This saves the effort of manually entering large numbers of points in regions where automatic operation is not feasible. By setting thresholds for an all black image, the system can be forced to remain in this mode until the trail configuration permits accurate automatic operation.

Option 06. If the problem is unique to a single point, as for example some adventitious transient, the point can simply be skipped. If the axis gets lost and wanders far from the trail, use of this option moves the axis back near the trail center.

Option 07. If the scan line intersects the trail in two or more places, the center pixel may be chosen at the wrong location. The situation is apparent from the monitor image. Entering 192 as the center pixel forces the center to be chosen at the optic axis and gets the system back onto the proper branch. The range of search for the background can also be limited at this time.

Option 08. If the scan intersects a problem area, its direction can be changed for one point to avoid the difficulty.

The information provided in requests for intervention should be sufficient for diagnosis of the problems that arise in automatic digitization and the options provided should constitute a sufficient armamentarium in getting past difficult areas. The most effective approach is to choose skeleton points in a manner which keeps the system in the automatic mode and thus avoids, as far as possible, the need for intervention.

D. Operator Initiated Interrupts

There are occasions when intervention or an abnormal sequence of operations may be appropriate although the system has made no request. During digitization the axis may be moving away from the trail, for example, because a power line surge has mimicked the

the effect of a trail edge. No request for intervention will be made in this circumstance. During setup, an error may occur requiring a change in the procedure.

In these - and other - circumstances, the operator may obtain control by setting 000413 on the switch register and executing the switch cycle: SI, KR, ENT, RUN. It is then possible to enter the main error routine or any of a number of points in the system program. The teletype prints:

DO YOU WANT A SPECIFIC SEGMENT? I2

The number of the segment - 01 through 16 - is entered followed by (CR). The procedure causes a branch to the program segment with a number one less than the number entered, and the system commences running from this point. Since values of all parameters remain unchanged, the operator does not have complete control of subsequent events. The actual result of each possible choice is as follows:

01 Teletype prints

REMOVE TRISYS TAPE - MOUNT DATA TAPE

and the system proceeds as if at Sept 10 of the operating procedure described in Section IV.

02 Teletype prints

DO YOU WANT A SPECIFIC SEGMENT? I2

and the operator can try again.

03, 04 The routines for locating triangular and plus fiducials respectively are entered

05 The routine for determining star coordinates is entered

06 Teletype prints

LRET = ? - I2

The operator enters a 2-digit number (01-06) with the result that control is transferred to various points in the skeleton trail entry routine as follows: LRET = 1:

Teletype prints

APPROXIMATE TRAIL ENTRY PROGRAM

and then proceeds as for LRET-2.

LRET = 2 or 4: Number of skeleton point is incremented, then teletype prints two dots and enables the joystick; skeleton points can be entered.

LRET = 3: Number of skeleton point is reset to 1; subsequent flow is the same as for LRET = 2.

LRET = 5: Control goes to a point in the star location program; ultimately the same point as for segment 02 is reached.

LRET = 6: Another point in the star location routine is reached.

07 The tape output routine is entered, with unpredictable results. Eventually the teletype prints

ENTER INCREMENT IN STAGE SETPS I3

08 An error processing routine is entered, with unpredictable results.

09, 10 The routine for locating the frame center without fiducial marks entered (for 10 the routine is entered at its midpoint).

Teletype prints

MOVE STAGE TO TOP LEFT OF FRAME-TYPE CR
FOR 09 or

MOVE STAGE TO LEFT CENTER EDGE-TYPE CR
FOR 10.

Using 10 allows rotational alignment to be bypassed.

11 The beginning of the trail digitization routine (TDR) is entered:

The teletype prints

ENTER DELTA X IN STAGE STEPS - I2

12, 13 Various parts of the TDR are entered, with unpredictable results.

14 The main error routine is entered. The standard message is printed, and the regular options can be entered. This error routine is thus available to the operator at any time he feels the system is not doing well in automatic mode.

15, 16 Portions of the TDR are entered. The results are unpredictable.

REFERENCES

1. N.W. Rosenberg, Application of a Computer-Controlled Two-Dimensional Densitometer to Photograph Chemical Releases, AFCRL-TR-73-0155, 9 March 1973.

APPENDIX A

Program Control

Long term storage of the system program is on magnetic tape; for operation, this program must first be read onto the disk. The program size exceeds the computer core capacity, so program segments are moved into core from the on-line disk when required. The parts of the system programs are described in Appendix B. Parts 1-5 are always in core. Each of the sixteen segments which are rotated into core on demand is a FORTRAN subroutine named TRIS. They are called by Subroutine FTLOD, which is permanently in core. When Segment i wishes to transfer control to Segment j, it sets variable KKK equal to J + 1 and yeilds control to FTLOD via a RETURN statement. The value of KKK is transmitted through COMMON storage, and sets the value of the index of an array on FTLOD containing the disk addresses of the segments of TRIS. FTLOD loads the specified segment into core and calls TRIS, thus transferring control to Segment j which has just been loaded. Another variable, LRET, may be transmitted through COMMON storage to specify the portion of Segment j to which control will pass.

APPENDIX B

Program Segments

1. Index. Lists routines in system.

2. Loader (FTLOD) has two functions. One is to load the rest of the program onto the disk from magnetic tape. The second is to swap program segment between disk and core as described in Appendix A. Thus FTLOD is entered whenever control shifts to a different segment of the program. The parameters KKK and LRET, transmitted through COMMON, determine the next routine to be loaded into core and the portion of the routine to which control will be transferred.

3. Dummy. Includes a number of calls which are never executed; the purpose is to be sure of proper ordering of routines loaded from the system library. This is actually the main program but it immediately calls FTLOD and is never reentered.

4. MOVSTG. Sets up commands for transmission through the microprocessor (See Appendix D) to the stage controls and this determines motions to be made. This routine is permanently in core and can therefore be called from any segment and can later return control efficiently to the same point.

5. ASCII Dump. Prints data from tape.

   The following 16 segments each named TRIS (KKK), are loaded onto core as needed, and are overwritten when they give up control.

6. Segment 0 TRIS (1). Initializes the program.

7. Segment 1 TRIS (2). At the beginning of a run, or at the end of a task, requests information from the operator as to what to do next. A branch to any segment can be commanded at this

point. If flow proceeds normally, a data file number is entered and thresholds are set. The stage is moved to the left side fiducial and control is transferred to the appropriate routine for the type of fiducial specified by the operator. Operator-initiated intervention (See V-D) transfers control to this routine.

8. Segment 2 TRIS (3). Triangular fiducials are located, rotational misalignment corrected, and the coordinate system defined.

9. Segment 3 TRIS (4). Plus fiducials are located, rotational misalignment corrected, and the coordinate system defined.

10. Segment 4 TRIS (5). Finds the position of a star, used for accurate aspect determination. Approximate positions of up to 50 stars as either points or short arcs are entered using the joystick. In the case of points, the system finds a star in a small box centered at the approximate position. For star arcs, approximate positions are entered as for trails as described below.

11. Segment 5 TRIS (6). Locations of the skeleton points are stored as entered using the joystick. The operator can delete the previous point, list all preceding points, enter another point, or exit from the routine. This program is called in digitizing either trails or star arcs.

12. Segment 6 TRIS (7). Coordinates of trail arcs or points are output to magnetic tape using ASCII code.

13. Segment 7 TRIS (8). Several conversational chores are accomplished, depending on the program from which the segment was called. The segment may;

    1. ask for type of fiducial mark and transfer to appropriate segment.
    2. print location of fiducials, reset coordinates and move to frame center; then ask whether the task is star calibration or trail trace and route appropriately.

3. request trail identifier and write it on output tape.

4. write out star coordinates.

5. writ.: out coordinates of edges of photographic frame, then branch to trail or star routine.

6. determine the star position as the center of an arc segment.

14, 15 Segment 8, 9 TRIS (9-10). Frame coordinates are specified for the case where there are no fiducial marks. In Part I, the rotational misalignment is corrected by locating two points along the top edge of the frame. In Part II, the left, right and bottom edges are located.

16-21 Segments 10-15 TRIS (11-16). This trail center digitization routine is written in six parts. In Part I (KKK = 11 Δx is entered and the axis moved to the first skeleton point. The slope of the line to the next skeleton point is determined, and the scan direction chosen. The point of minimum value is the approximate trail center; if it is offset by more than 20 pixels. Part IV, the main error routine, is entered. Checks are also made for excessive high digital value (white) and excessive low digital value (black), for insufficient trail to background range, and for multiple maxima and minimum. In Part II (KKK = 12) the multiple max-min test is completed. Approximate trail edges are located and the axis moved to the position of each in turn. In Part III (KKK = 13) the final trail edges are located for horizontal or vertical scan direction and their midpoint defined as the trail center. The axis is moved to this point and Segment 6 accessed to write the stage coordinates on magnetic tape; then control is returned to Part III to determine the starting point for the next location. Control passes to Part I, the axis is moved to this new starting point, and the process is repeated. Part IV (KKK = 14) is entered when operator intervention is needed. The option to be used is requested after certain diagnostic information has been printed. In Part V (KKK = 15) certain of the options are effected, including entering of joystick values or of a new background, threshold change, interpolation toward the next skeleton point and ignoring the troublesome point. Excessive off-scale data and insufficient density range are also handled in this part. In Part VI (KKK = 16), fine location of the trail edge for diagonal scan direction is effected. This part is also entered for an additional shear test during fine location.

APPENDIX C

Microprocessor

The microprocessor controls the flow of information involving the computer, paper tape reader, teletype, stage driver and joystick. Stage commands and teletype messages originate at the computer as FORTRAN formulated WRITE statements. When a data stream arrives from the computer, the first four characters are compared with the string STGC. If they do not match, the buffer contents are treated as a teletype message and are printed.

If the data stream is identified as a stage command by beginning with the characters STGC, the fifth (function) character specifies the routine to be entered. If the function character is

1. the stage drive x register is reset to zero
2. the stage driver y register is reset to zero
3. a stage motion is commanded; the coordinates of the move are specified by the variables NX, NY
4. the joystick is enabled
5. the joystick is disabled.

The function character is defined by the value of the FORTRAN variable IFU in the computer subroutine MOVSTG. IFU = 3, the signs and sizes of the X motion and Y motion respectively are extracted from the data stream and output to the stage controller. The stage is then commanded to start moving in the correct directions along the X and Y axes. When the motions are complete, the controller signals the microprocessor.

When the task specified by IFU has been completed, the signs and values of the stage drive X- and Y- registers are output to the computer. When MOVSTG has commanded any stage function it waits for this position information to be returned and reads it before proceeding. The position is thus always available, as the variable LXCORD and LYCORD, except when the joystick is enabled. After joystick operation, the operator types (CR). This computer which has been waiting at a READ statement then precedes and reads new LXCORD LYCORD values.

The microprocessor also controls the rate of motion in response to joystick commands. This rate is proportional to time; that is the stage moves one step in the first time unit, two in the second, four in the third, and so forth up to a maximum of 1024 steps per time unit. The time unit is currently 0.5 second.

APPENDIX D

Master Program Tape

```
1
TAPE PRESENTLY CONTAINS:
FILE PROGRAM LOADER SEGMENTS START

  3  RESDNT    0       0      17000
  4  CONFRM    0       2      17000
  5  GRID      0       1      00400
  6  BACKGD    0       1      00400
  7  VIDEOX    0       1      00400
  8  CONTUR    0       1      00400
  9  SEARCH    0       1      00400
 10  FORTRN    0       1      00012
 11  ELOAD     0       1      14000
 12  FORLIB    2       0      00000
 13  UPDIR     0       1      00400
 14  MTCOPY    0       1      00400
 15  AVGDT     0       1      00400
 16  DMAPA     0       1      00010
 17  TTYTAP    0       1      01000
 18  TDUMP     0       1      00400
 19  AEROCK    0       1      01003
 20  TSEG0     0       1      00410
 21  TSEG1     0       1      00404
 22  TSEG2     0       1      00404
 23  TSEG3     0       1      00404
 24  TSEG4     0       1      00404
 25  TSEG5     0       1      00404
 26  TSEG6     0       1      00404
 27  TSEG7     0       1      00404
 28  TSEG8     0       1      00404
 29  TSEG9     0       1      00404
 30  TSEG10    0       1      00404
 31  TSEG11    0       1      00404
 32  TSEG12    0       1      00404
 33  TSEG13    0       1      00404
 34  TSEG14    0       1      00404
 35  DUM1      0       1      00404
 36  SPECA1    0       1      00400
 37  TURBC1    0       1      00400
 38  MTCOP1    0       1      00400
 39  DSKCK1    0       1      00400
 40  LSQGA1    0       1      00400
 41  CONVT1    0       1      00400
EXECUTION COMPLETED

PROGRAM NAME:
```